

Somatosensory evoked potentials and cerebrospinal fluid flow in chiari malformation

Somatosensory evoked potentials in chiari malformation

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Abstract

Aim: Many studies reported that the degree of tonsillar herniation does not correlate with the severity of symptoms in Chiari Malformation Type 1 patients. The aim of this study is to investigate the relationship between tonsillar herniation, Cerebrospinal Fluid (CSF) flow and Somatosensory Evoked Potentials (SEP) in Chiari Malformation Type 1 patients. **Material and Method:** We have retrospectively reviewed 27 patients which had Chiari Malformation at our clinic. There were 7 men (25.3%) and 20 female (74.1%) with a mean age of 38 (range 15-62) years. **Results:** Fourteen patients (51.9%) had tonsillar ectopia 0-5mm, 13 patients had tonsillar ectopia over 5mm (48.9%). CSF flow abnormality was found in 13 patients (48.1%) and SEP abnormality in 6 patients (22.2%). In all patients clivus, supraoccipital, cerebellum hemisphere, Mc Rae line, Twinning line lengths and tentorium Twinning angle, Welcher basal angle, Boogaard angle were measured. There was no significant difference between tonsillar ectopia degree and abnormal SEP. Six patients who had abnormal SEP also had CSF flow abnormality ($p<0.05$). There was a significant difference between SEP and platybasia ($p<0.05$). Of the 27 patients, 5 were operated. There was statistical difference between CSF flow, tonsillar ectopia, and surgery ($p<0.05$). **Discussion:** The presence of CSF flow disorder in Chiari symptomatic patients is a finding of a hypoplastic posterior fossa. CSF flow disorder was associated with tonsillar ectopia. Despite the high rate of platybasia in patients with SEP disorder, more studies should be done in the future.

Keywords

Cerebrospinal Fluid Flow; Chiari Malformation; Morphometric; Somatosensory Evoked Potentials

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Introduction

Diagnosis and treatment of Chiari malformation (CM) are highly influenced by the neuroradiological criteria. The most common neuroradiological signs are hypoplasia of posterior fossa and tonsillar ectopia (TE) of varying degrees. In Type 1 Chiari Malformation (CM1), more than 3 or 5 millimeters downward displacement of the tonsils through the foramen magnum (FM) is considered as diagnostic criteria [1]. Barkovich and colleagues stated that for the diagnosis of CM1 tonsillar herniation more than 3 millimeters is essential, however, several studies emphasized there is no relation between the degree of herniation and the severity of symptoms or the presence of a syrinx [2,3]. Besides, 30-65% of the patients with syringomyelia have the signs of compressed posterior fossa with the minimal herniation or without any tonsillar herniation [4].

Nowadays with the extensive use of Magnetic Resonance Imaging (MRI), diagnosis of incidental CM1 is increased. Iskandar et al. defined CM 0 in 5 pediatric cases as presence of a syrinx and a condensed posterior fossa, some authors stated the absence of cisterna magna [5]. CM 1.5 is defined as the caudal displacement of the brainstem in addition to the tonsillar herniation by Tubbs et al. [6,7].

MRI is used in the evaluation of the neural and dural structures as well as the subarachnoid space in the posterior fossa, also allows morphometric analysis. Additionally, MRI allows the evaluation of Cerebrospinal Fluid (CSF) dynamics [8]. The symptoms of CM are mostly related with disrupted CSF dynamics. Compression of subarachnoid space in the posterior fossa, displacement of the CSF and the relation with the development of a syrinx, worsening symptoms with valsalva maneuver, suboccipital headache, pseudotumor cerebri-like and Meniere-like complaints are the clues of disrupted CSF dynamics [1].

Evoked potential (EP) studies are not a routine in CM1 patients. However, the changes in Brainstem Auditory Evoked Potentials (BAEP) and Somatosensory Evoked Potentials (SEP) may give valuable information in ventral brainstem compression [9]. SEP waves acquired from the central recordings of the posterior tibial nerve for the lower extremity and median nerve for the upper extremity enables the evaluation of medial lemniscus in the dorsal column of the spinal cord. Abnormal findings may alter the follow-up of asymptomatic patients or patients with Chiari-like symptoms as well as the surgical decision in patients with low-grade tonsillar ectopy and compressed posterior fossa accompanied by a syrinx.

The aim of this study is to assess the contribution of the morphometric analysis, evaluation of CSF flow dynamics and SEP for the diagnosis of patients with tonsillar herniation of varying degree.

Material and Method

Twenty-seven patients with tonsillar ectopia treated between years of 2012 and 2017 were examined and included in this retrospective study. Ethical approval was obtained at our institution (31829978-050.01.04-E.1700069899 and decision numbered 185). The correlation between morphometric analysis on MRI and the results of SEP and CSF-flow MRI were analyzed. The cases were grouped into two as tonsillar ectopia between 0-5 millimeters and above 5 millimeters and the results men-

tioned were compared. The rates of basilar invagination (BI) and platybasia were determined as commonly accompanying CM. The relation between the results of the functional studies and presence of the accompanying anomalies were analyzed. The age, sex, symptoms, presence of syringomyelia and hydrocephalus (normal, mild, moderate, severe) and history of surgery of the patients were noted.

The standard measurement methods stated in the literature were used for the morphometric measurements. The original Brain MRI images of the patients on the PACS (Picture Archiving and Communication System) system of our hospital were utilized. The images were in DICOM format. T1 and T2-weighted sagittal midline images were used for linear and angular measurements. The unit of measure was millimeters for length and degrees for the angle.

The parameters evaluated according to the standard measurement methods were: portion of tonsillar ectopia (TE): the amount of herniation of cerebellar tonsils through FM, length of clivus, the length of supra occiput (SO): the length between opisthion- the posterior margin of FM and internal occipital protuberance (IOP), Mc Rae's line: the line between anterior and posterior margins of FM, Twining's line: the length between the uppermost point of dorsum sella and IOP, the angle between Twining's line and tentorium, the position (below, above, level with) of the odontoid tip relative to Chamberlain's line and the distance to the line as millimeters, the degree of BI: the minimum distance of odontoid tip to Chamberlain's line was measured according to 3 criterias as suggested; above 2 millimeters, above 5 millimeters, above 6.6 millimeters, Welcher's basal angle: the angle between a line extending from planum sphenoidale crossing with another line extending from clivus (105-127 degrees: normal, below 105 degrees: basillar kyphosis, above 127 degrees: platybasia), Boogaard's angle: the angle between clivus and Mc Rae's line (above 136 degrees: platybasia) (Figure 1).

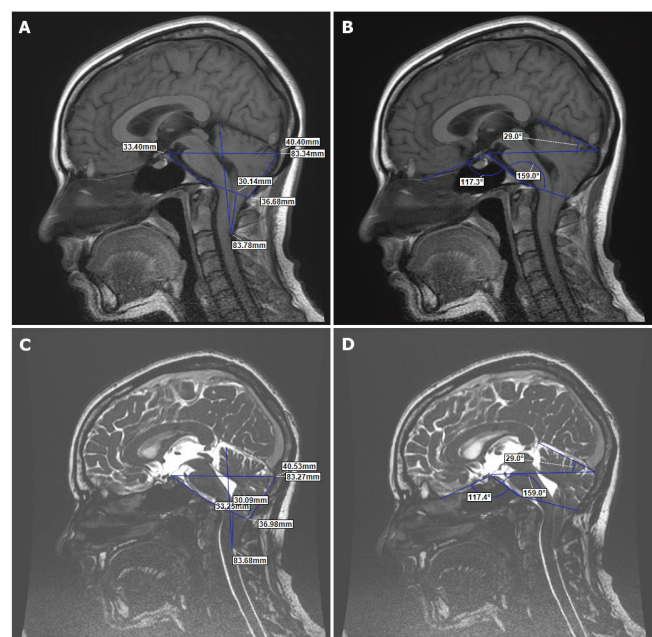


Figure 1. T1 and T2 sagittal midline MRI of the patient.

A) Tonsillar ectopia: 30.14 mm, Mc-Rea line:36.68 mm, Clivus length: 33.40 mm, Supra occiput length: 40.40 mm, cerebellar hemisphere length: 83.78 mm, Twining line: 83.34 mm B) Welcher basal angle: 117.30, Boogaard angle: 159.0, Tentorium Twining angle: 290

For the diagnosis of BI, the measurements were done according to three different criteria as follows: the position of the odontoid tip relative to Chamberlain's line above 2 millimeters, above 5 millimeters and above 6 millimeters. Welcher's basal angle and Boogaard's angle were used to determine the ratio of platybasia.

The CSF-flow analysis was done via qualitative measurements of perimedullary CSF flow disturbances on FM level and parameters (normal, mildly decreased posteriorly, noticeably decreased posteriorly, noticeably decreased premedullary) with phase contrast CSF-flow MRI's of the patients (Figure 2).

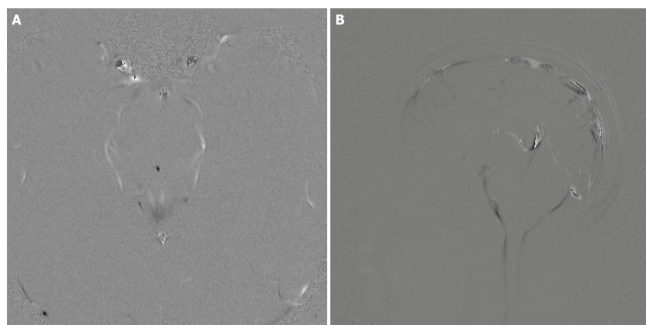


Figure 2. Patient phase contrast CSF MRI results. A) phase contrast axial image CSF systole (hyperintense) and marked decrease in flow at posterior subarachnoid space B) phase contrast sagittal image of CSF systole (hypointense) and marked decrease in flow at posterior subarachnoid space

The results of SEP performed in the neurophysiology laboratory of our hospital were evaluated retrospectively. For the upper extremity (fasciculus cuneatus) SEP, N24 wave of cerebral recordings gathered from stimulation of median nerve (MN) bilaterally on the wrist was used. For the lower extremity (fasciculus gracilis) SEP, P45 wave of cerebral recordings from stimulation of posterior tibial nerve on the medial malleolus bilaterally was evaluated (Figure 3).

The analyses were done using IBM SPSS (Statistical Package for the Social Sciences) 15.0 (Chicago, USA) package program. Mean ± standard deviation were used as descriptive statistics. Chi-square and Fischer exact tests were used for statistical analysis; and p<0.05 was accepted as statistically significant.

Results

Among 27 patients with tonsillar ectopia 20 (74.1%) were females and 7 (25.9%) were males. The mean age was 38 ± 12.66 (range 15- 62). The most common symptom was a headache seen in 19 (70.4%) patients. Other symptoms were neck pain (40.7%), dizziness (14.8%), alteration of sensation on the extremities (14.8%). In those 27 patients, 14 (51.9%) of them had tonsillar ectopia between 0-5 millimeters and 13 (48.1%) had more than 5 millimeters. The mean measure of tonsillar ectopia was 7.14 ± 6.22 mm.

According to the linear morphometric measurements taken on the sagittal midline T1 and T2 MRI the mean clivus length was 39.77 ± 3.42 mm, the mean length of supra occiput (SO) was 40.29 ± 3.65 mm, the mean length of cerebellar hemisphere was 61.16 ± 6.75mm , the mean length of Mc Rae's line was 32.46 ± 2.60 mm, the mean length of Twining's line was 79.51 ± 4.93 mm (Table 1).

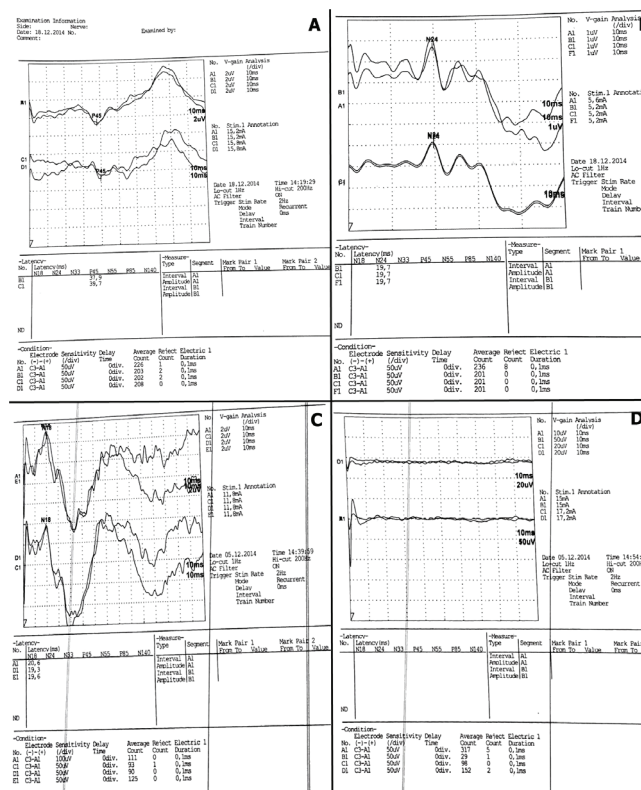


Figure 3. A) On the cerebral recordings obtained from the ankle stimulation of median nerve, 19.7 msn on the right, 19.7 ms N20 on the left, bilateral normal transmission on the fasciculus kuneatus. B) The cerebral recordings obtained by stimulation of posterior tibial nerve at the inner malleol level were 37.9 ms on the right, 39.7 ms P40 on the left, bilateral normal transmission on the fasciculus gracilis C) On the cerebral recordings obtained from the ankle stimulation of median nerve, 19.3 ms on the right, 19.6 ms on the left N20 wave, bilateral normal transmission in the fasciculus cuneatus D) No response was obtained in cerebral recordings obtained by stimulation of PTN at the level of bilateral internal malleolus. bilateral transmission block on the fasciculus gracilis.

Table 1. Morphometric measurement results

Morphometric Measurement results (N=27)	Mean (mm or Degree)
Tonsillar ectopia (mm)	7.14±6.22
Basilar invagination (mm)	12.11±13.93
Above Chamberlain's line (mm)	2.85±1.40
Clivus length (mm)	39.77±3.42
Supraocciput length (mm)	40.29±3.65
Cerebellar hemisphere length (mm)	61.16±6.75
Mc Rae's line (mm)	32.46±2.60
Twining line (mm)	79.51±4.93
Tentorium-Twining angle (°)	40.18±6.99
Welcher's basal angle (°)	116.88±5.44
Boogaard angle (°)	128.88±9.05

When the upper and lower extremity SEP results evaluated there was an abnormality in 6 patients (22.2%). Among these 6 patients, 1 patient had a block of conduction bilaterally in the upper extremities and 5 patients had normal conduction. In lower extremity, there was prolonged conduction bilaterally in 2 patients, block of conduction bilaterally in 2 patients and block of conduction on the left side in 2 patients (Table 2).

Five patients (18.5%) were operated. All of those patients had tonsillar ectopia more than 5 millimeters. Standard decompression procedure (suboccipital craniectomy and/or C1 laminectomy)

Table 2. Distribution of morphometric and functional characteristics of 27 patients with Tonsillar ectopia

	Patient (N)	%
Tonsillar ectopia		
0-5mm	14	51.9
≥6mm	13	48.1
Odontoid tip -Chamberlain's line relationship		
Above	9	33.3
Lower	14	51.9
Same line	4	14.8
Basilar invagination (criteria 2mm)	3	18.5
Basilar invagination (criteria 5mm)	2	7.4
Basilar invagination (criteria 6mm)	1	3.7
According to Boogaard Angle-Platybasia (≥136°)	5	18.5
According to Welcher Basal Angle		
≤105 (Basilar kyphosis)	1	3.7
105-127 (Normal)	26	96.3
≥127 (Platybasia)	0	0
CSF flow abnormality	13	48.1
CSF flow		
Posterior minimal reduction	6	22.2
Posterior severe reduction	3	11.1
Perimedullary severe reduction	4	14.8
SEP abnormality		
Upper ext. normal -bilateral lower ext. block of conduction	2	7.4
Upper ext. normal -bilateral lower ext. Prolonged of conduction	1	3.7
Upper ext. normal -left lower ext. block of conduction	2	7.4
Bilateral Upper ext. block of conduction- bilateral lower ext. Prolonged of conduction	1	3.7
Syrinx	8	29.6
Hydrocephalus	1	3.7
Surgery	5	18.5

tomy + duraplasty) was performed.

Linear morphometric measurements of the patients with TE between 0-5 millimeters and greater than 5 millimeters are compared. There was not any significant difference between two groups in terms of mean lengths of clivus, supra occiput (SO), cerebellar hemisphere, Mc Rae's line and Twining's line ($p>0.05$).

When the angular measurements of those two groups were compared there was no difference in the mean values of the angle between tentorium and Twining's line ($p=0.148$), Welcher's basal angle ($p=1.000$), and Boogaard's angle ($p=0.470$).

There was no significant difference between the degree of TE and the presence of a syrinx ($p=0.248$) or hydrocephalus ($p=1.000$). Among all operated patients the TE was greater than 5 millimeters ($p=0.011$).

The degree of TE, presence of CSF flow disturbance and SEP abnormality were compared. There was a CSF flow disturbance in 13 patients (48.1%) and SEP abnormality in 6 patients (22.2%). Among 13 patients with CSF flow disturbance, the degree of TE was greater than 5 millimeters in 8 patients and between 0-5 millimeters in 5 patients. In 6 of 13 patients, there was a SEP abnormality. There was no SEP abnormality in patients without any CSF flow disturbance. A significant rela-

tionship between the presence of CSF flow disturbance and the degree of TE ($p=0.038$) was revealed. Also, there was a relationship between the presence of CSF flow disturbance and the presence of SEP abnormality ($p=0.016$).

In 14 patients (51.9%) the odontoid tip was above the Chamberlain's line. According to 2 millimeters criteria there was BI in 5 (18.5%) patients. There was platybasia in 5 patients when evaluated by Boogaard's angle. The presence of platybasia and CSF flow disturbance additionally the presence of SEP abnormality were compared. Among 5 patients with platybasia, there was also CSF flow disturbance in 4 patients ($p=0.045$) and there was SEP abnormality in 4 patients ($p=0.004$). The rates of CSF flow abnormality and presence of SEP abnormality were higher in patients with platybasia.

Discussion

The MRI findings of paraxial mesoderm defect in CM1 have decreased supra occiput length, increased slope of tentorium, hypoplasia of clivus and craniovertebral junction abnormalities. Other findings are related to the condensed posterior fossa. The most common abnormality is the compression of subarachnoid space on the posterior and lateral portions of the cerebellum. In our study, there was no significant correlation between the degree of TE and the mean values of linear measurements. When compared with the measurements on the literature, the mean clivus length was shorter in our study (39.77 ± 3.42) than the mean measurement in healthy control groups in other studies (Sekula and colleagues, 43 millimeters; Yan and colleagues, 51.6 millimeters; Houston and colleagues, 42.4 millimeters) [10-12].

The ratio of BI was 6% in a study by Milhorat and colleagues [1]. Higher ratios of 23.9% and 65.6% from different studies were also reported [13,14]. In our study, in 51.9% of the patients odontoid tip is above Chamberlain's line. According to the defined criterias the ratio was 18.5% (2 millimeters as the criteria), 7.4% (5 millimeters as the criteria), and 3.7% (6 millimeters as the criteria).

CSF-flow MRI presents the bidirectional flow of CSF during a cardiac cycle and gives valuable information about CSF dynamics. Gretz and colleagues showed this pulsatile movement using phase-contrast MRI [15]. During systole, CSF moves caudally due to the increased cerebral blood volume and moves cranially during diastole. The flow in the same direction with the selected one on the directional phase-contrast image is seen as hyperintense and the flow in the opposite direction seen as hypointense. It's seen isointense when there is no flow. The CSF-flow studies demonstrated the pathological CSF flow on FM level in CM1 due to the condensed posterior fossa and compressed subarachnoid space [16]. In asymptomatic patients with normal CSF flow on FM level, follow-up without surgery may be considered. A syrinx may develop due to the movement of CSF via perivascular and interstitial space as a continuum of anatomical structures towards central canal of spinal cord. This movement may arise from exaggerated increment of pulsatile systolic waves resulting from CSF flow obstruction of FM level. In severe cases, hydrocephalus may develop [17]. In our study, the ratio of CSF-flow disturbance was 48.1% and the presence of a syrinx was 29.6%.

BAEP and SEP studies are not routines in patients with CM1. The first study related with CM1 belongs to Anderson and colleagues. Restuccia and Mouguiere have SEP studies in patients with syrinx. They showed the most common abnormality as alteration or absence of cervical potentials. In those two studies, the ratio of the presence of a syrinx was 100% [18,19].

SEP evaluates medial lemniscus located in the dorsal column of the spinal cord. Medial lemniscus is affected when there is a severe ventral impression or in patients with an advanced syrinx. Abnormal conduction on somatosensory pathways demonstrates an abnormal function of brainstem and/or upper cervical cord. With SEP technique brainstem dysfunction can be distinguished by a high sensitivity and specificity. Barnett and colleagues stated that it may be less reliable in children and young adults, additionally, BAEP could be more valuable in neonates and infants [20,21].

In a cohort study with 547 patients, Moncho and colleagues researched the value of SEP in the decision-making process regarding treatment and follow-up in incidental oligo-symptomatic classical CM1 cases without remarkable ventral compression and BI. Patients with CM0, CM1 and CM1.5 were included to that study. They found SEP changes in 43.5% of the patients. The ratio of PTN abnormality was 37% and MN abnormality was 22.5%. They stated that there was a significant correlation with increasing age and the degree of tonsillar ectopia. When divided into the subtypes, the ratio of SEP abnormality was 51.1% in patients with CM1, 64.3% in patients with CM0 (the patients with a syrinx were also greater in number in this subtype) and 34.7% in patients with CM1.5 [22]. In our study, the ratio of SEP abnormality was 22.2%. Abnormalities in PTN are much more frequent than in MN. There was a significant correlation between CSF flow disturbance and the degree of TE ($p=0.038$) and the presence of SEP abnormality ($p=0.016$). CSF flow disturbance and SEP abnormality are more frequently seen in patients with platybasia and there was a significant correlation for both. Neuronal dysfunction of the brain stem, cerebellum, cranial nerves and upper cervical spinal cord may be seen in all subtypes of CM. The respiratory center and the afferent and efferent routes of this center are located at the craniovertebral junction. The function of this center may be impaired in patients with CM. In the incidental cases, the presence of sleep apnea or hypopnea may alter the surgical decision [23].

Presence of CSF flow disturbance in patients with CM is a sign of a hypoplastic and condensed posterior fossa. Although there was no significant difference in terms of morphometric measurements between the patients with TE greater than 5 millimeters and the patients with TE 0-5 millimeters, presence of CSF flow disturbance was correlated with the degree of TE. There was also a correlation between CSF flow disturbance and presence of SEP abnormality. The ratio of platybasia was higher in patients with SEP abnormality or CSF flow disturbance. Basal angular measurements and functional studies aid the diagnosis and surgical decision-making in symptomatic patients. They may aid to determine the prognosis and follow-up in incidental asymptomatic patients. SEP studies in a larger study group and sleep disturbance studies should be considered in the future.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest

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